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STUDIES FOR STUDENTS.

THE METHOD OF MULTIPLE WORKING HYPOTHESES.¹

THERE are two fundamental modes of study. The one is an attempt to follow by close imitation the processes of previous thinkers and to acquire the results of their investigations by memorizing. It is study of a merely secondary, imitative, or acquisitive nature. In the other mode the effort is to think independently, or at least individually. It is primary or creative study. The endeavor is to discover new truth or to make a new combination of truth or at least to develop by one's own effort an individualized assemblage of truth. The endeavor is to think for one's self, whether the thinking lies wholly in the fields of previous thought or not. It is not necessary to this mode of study that the subject-matter should be new. Old material may be reworked. But it is essential that the process of thought and its results be individual and independent, not the mere following of previous lines of thought ending in predetermined results. The demonstration of a problem in Euclid precisely as laid down is an illustration of the former; the demonstration of the same proposition by a method of one's own or in a manner distinctively individual is an illustration of the latter, both lying entirely within the realm of the known and old.

Creative study however finds its largest application in those subjects in which, while much is known, more remains to be learned. The geological field is preëminently full of such sub-

¹A paper on this subject was read before the Society of Western Naturalists in 1892, and was published in a scientific periodical. Inquiries for the article have recently been such as to lead to the belief that a revision and republication are desirable. The article has been freely altered and abbreviated so as to limit it to aspects related to geological study.

jects, indeed it presents few of any other class. There is probably no field of thought which is not sufficiently rich in such subjects to give full play to investigative modes of study.

Three phases of mental procedure have been prominent in the history of intellectual evolution thus far. What additional phases may be in store for us in the evolutions of the future it may not be prudent to attempt to forecast. These three phases may be styled the method of the ruling theory, the method of the working hypothesis, and the method of multiple working hypotheses.

In the earlier days of intellectual development the sphere of knowledge was limited and could be brought much more nearly than now within the compass of a single individual. As a natural result those who then assumed to be wise men, or aspired to be thought so, felt the need of knowing, or at least seeming to know, all that was known, as a justification of their claims. So also as a natural counterpart there grew up an expectancy on the part of the multitude that the wise and the learned would explain whatever new thing presented itself. Thus pride and ambition on the one side and expectancy on the other joined hands in developing the putative all-wise man whose knowledge boxed the compass and whose acumen found an explanation for every new puzzle which presented itself. Although the pretended compassing of the entire horizon of knowledge has long since become an abandoned affectation, it has left its representatives in certain intellectual predilections. As in the earlier days, so still, it is a too frequent habit to hastily conjure up an explanation for every new phenomenon that presents itself. Interpretation leaves its proper place at the end of the intellectual procession and rushes to the forefront. Too often a theory is promptly born and evidence hunted up to fit in afterward. Laudable as the effort at explanation is in its proper place, it is an almost certain source of confusion and error when it runs before a serious inquiry into the phenomenon itself. A strenuous endeavor to find out precisely what the phenomenon really is should take the lead and crowd back the question, commend-

able at a later stage, "How came this so?" First the full facts, then the interpretation thereof, is the normal order.

The habit of precipitate explanation leads rapidly on to the birth of general theories.¹ When once an explanation or special theory has been offered for a given phenomenon, self-consistency prompts to the offering of the same explanation or theory for like phenomena when they present themselves and there is soon developed a general theory explanatory of a large class of phenomena similar to the original one. In support of the general theory there may not be any further evidence or investigation than was involved in the first hasty conclusion. But the repetition of its application to new phenomena, though of the same kind, leads the mind insidiously into the delusion that the theory has been strengthened by additional facts. A thousand applications of the supposed principle of levity to the explanation of ascending bodies brought no increase of evidence that it was the true theory of the phenomena, but it doubtless created the impression in the minds of ancient physical philosophers that it did, for so many additional facts seemed to harmonize with it.

For a time these hastily born theories are likely to be held in a tentative way with some measure of candor or at least some self-illusion of candor. With this tentative spirit and measurable candor, the mind satisfies its moral sense and deceives itself with the thought that it is proceeding cautiously and impartially toward the goal of ultimate truth. It fails to recognize that no amount of provisional holding of a theory, no amount of application of the theory, so long as the study lacks in incisiveness and exhaustiveness, justifies an ultimate conviction. It is not the slowness with which conclusions are arrived at that should give satisfaction to the moral sense, but the precision, the completeness and the impartiality of the investigation.

¹I use the term theory here instead of hypothesis because the latter is associated with a better controlled and more circumspect habit of the mind. This restrained habit leads to the use of the less assertive term hypothesis, while the mind in the habit here sketched more often believes itself to have reached the higher ground of a theory and more often employs the term theory. Historically also I believe the word theory was the term commonly used at the time this method was predominant.

It is in this tentative stage that the affections enter with their blinding influence. Love was long since discerned to be blind and what is true in the personal realm is measurably true in the intellectual realm. Important as the intellectual affections are as stimuli and as rewards, they are nevertheless dangerous factors in research. All too often they put under strain the integrity of the intellectual processes. The moment one has offered an original explanation for a phenomenon which seems satisfactory, that moment affection for his intellectual child springs into existence, and as the explanation grows into a definite theory his parental affections cluster about his offspring and it grows more and more dear to him. While he persuades himself that he holds it still as tentative, it is none the less lovingly tentative and not impartially and indifferently tentative. So soon as this parental affection takes possession of the mind, there is apt to be a rapid passage to the unreserved adoption of the theory. There is then imminent danger of an unconscious selection and of a magnifying of phenomena that fall into harmony with the theory and support it and an unconscious neglect of phenomena that fail of coincidence. The mind lingers with pleasure upon the facts that fall happily into the embrace of the theory, and feels a natural coldness toward those that assume a refractory attitude. Instinctively there is a special searching-out of phenomena that support it, for the mind is led by its desires. There springs up also unwittingly a pressing of the theory to make it fit the facts and a pressing of the facts to make them fit the theory. When these biasing tendencies set in, the mind rapidly degenerates into the partiality of paternalism. The search for facts, the observation of phenomena and their interpretation are all dominated by affection for the favored theory until it appears to its author or its advocate to have been overwhelmingly established. The theory then rapidly rises to a position of control in the processes of the mind and observation, induction and interpretation are guided by it. From an unduly favored child it readily grows to be a master and leads its author whithersoever it will. The subsequent history of that mind in respect to that

theme is but the progressive dominance of a ruling idea. Briefly summed up, the evolution is this : a premature explanation passes first into a tentative theory, then into an adopted theory, and lastly into a ruling theory.

When this last stage has been reached, unless the theory happens perchance to be the true one, all hope of the best results is gone. To be sure truth may be brought forth by an investigator dominated by a false ruling idea. His very errors may indeed stimulate investigation on the part of others. But the condition is scarcely the less unfortunate.

As previously implied, the method of the ruling theory occupied a chief place during the infancy of investigation. It is an expression of a more or less infantile condition of the mind. I believe it is an accepted generalization that in the earlier stages of development the feelings and impulses are relatively stronger than in later stages.

Unfortunately the method did not wholly pass away with the infancy of investigation. It has lingered on, and reappears in not a few individual instances at the present time. It finds illustration in quarters where its dominance is quite unsuspected by those most concerned.

The defects of the method are obvious and its errors grave. If one were to name the central psychological fault, it might be stated as the admission of intellectual affection to the place that should be dominated by impartial, intellectual rectitude alone.

So long as intellectual interest dealt chiefly with the intangible, so long it was possible for this habit of thought to survive and to maintain its dominance, because the phenomena themselves, being largely subjective, were plastic in the hands of the ruling idea ; but so soon as investigation turned itself earnestly to an inquiry into natural phenomena whose manifestations are tangible, whose properties are inflexible, and whose laws are rigorous, the defects of the method became manifest and an effort at reformation ensued. The first great endeavor was repressive. The advocates of reform insisted that

theorizing should be restrained and the simple determination of facts should take its place. The effort was to make scientific study statistical instead of causal. Because theorizing in narrow lines had led to manifest evils theorizing was to be condemned. The reformation urged was not the proper control and utilization of theoretical effort but its suppression. We do not need to go backward more than a very few decades to find ourselves in the midst of this attempted reformation. Its weakness lay in its narrowness and its restrictiveness. There is no nobler aspiration of the human intellect than the desire to compass the causes of things. The disposition to find explanations and to develop theories is laudable in itself. It is only its ill-placed use and its abuse that are reprehensible. The vitality of study quickly disappears when the object sought is a mere collocation of unmeaning facts.

The inefficiency of this simply repressive reformation becoming apparent, improvement was sought in the method of the working hypothesis. This has been affirmed to be *the* scientific method. But it is rash to assume that any method is *the* method, at least that it is the ultimate method. The working hypothesis differs from the ruling theory in that it is used as a means of determining facts rather than as a proposition to be established. It has for its chief function the suggestion and guidance of lines of inquiry; the inquiry being made, not for the sake of the hypothesis, but for the sake of the facts and their elucidation. The hypothesis is a mode rather than an end. Under the ruling theory, the stimulus is directed to the finding of facts for the support of the theory. Under the working hypothesis, the facts are sought for the purpose of ultimate induction and demonstration, the hypothesis being but a means for the more ready development of facts and their relations.

It will be observed that the distinction is not such as to prevent a working hypothesis from gliding with the utmost ease into a ruling theory. Affection may as easily cling about a beloved intellectual child when named an hypothesis as if named a theory, and its establishment in the one guise may

become a ruling passion very much as in the other. The historical antecedents and the moral atmosphere associated with the working hypothesis lend some good influence however toward the preservation of its integrity.

Conscientiously followed, the method of the working hypothesis is an incalculable advance upon the method of the ruling theory; but it has some serious defects. One of these takes concrete form, as just noted, in the ease with which the hypothesis becomes a controlling idea. To avoid this grave danger, the method of multiple working hypotheses is urged. It differs from the simple working hypothesis in that it distributes the effort and divides the affections. It is thus in some measure protected against the radical defect of the two other methods. In developing the multiple hypotheses, the effort is to bring up into view every rational explanation of the phenomenon in hand and to develop every tenable hypothesis relative to its nature, cause or origin, and to give to all of these as impartially as possible a working form and a due place in the investigation. The investigator thus becomes the parent of a family of hypotheses; and by his parental relations to all is morally forbidden to fasten his affections unduly upon any one. In the very nature of the case, the chief danger that springs from affection is counteracted. Where some of the hypotheses have been already proposed and used, while others are the investigator's own creation, a natural difficulty arises, but the right use of the method requires the impartial adoption of all alike into the working family. The investigator thus at the outset puts himself in cordial sympathy and in parental relations (of adoption, if not of authorship,) with every hypothesis that is at all applicable to the case under investigation. Having thus neutralized so far as may be the partialities of his emotional nature, he proceeds with a certain natural and enforced erectness of mental attitude to the inquiry, knowing well that some of his intellectual children (by birth or adoption) must needs perish before maturity, but yet with the hope that several of them may survive the ordeal of crucial research, since it often proves in the end that several agencies were con-

joined in the production of the phenomena. Honors must often be divided between hypotheses. One of the superiorities of multiple hypotheses as a working mode lies just here. In following a single hypothesis the mind is biased by the presumptions of its method toward a single explanatory conception. But an adequate explanation often involves the coördination of several causes. This is especially true when the research deals with a class of complicated phenomena naturally associated, but not necessarily of the same origin and nature, as for example the Basement Complex or the Pleistocene drift. Several agencies may participate not only but their proportions and importance may vary from instance to instance in the same field. The true explanation is therefore necessarily complex, and the elements of the complex are constantly varying. Such distributive explanations of phenomena are especially contemplated and encouraged by the method of multiple hypotheses and constitute one of its chief merits. For many reasons we are prone to refer phenomena to a single cause. It naturally follows that when we find an effective agency present, we are predisposed to be satisfied therewith. We are thus easily led to stop short of full results, sometimes short of the chief factors. The factor we find may not even be the dominant one, much less the full complement of agencies engaged in the accomplishment of the total phenomena under inquiry. The mooted question of the origin of the Great Lake basins may serve as an illustration. Several hypotheses have been urged by as many different students of the problem as the cause of these great excavations. All of these have been pressed with great force and with an admirable array of facts. Up to a certain point we are compelled to go with each advocate. It is practically demonstrable that these basins were river valleys antecedent to the glacial incursion. It is equally demonstrable that there was a blocking up of outlets. We must conclude then that the present basins owe their origin in part to the preëxistence of river valleys and to the blocking up of their outlets by drift. That there is a temptation to rest here, the history of the question shows. But

on the other hand it is demonstrable that these basins were occupied by great lobes of ice and were important channels of glacial movement. The leeward drift shows much material derived from their bottoms. We cannot therefore refuse assent to the doctrine that the basins owe something to glacial excavation. Still again it has been urged that the earth's crust beneath these basins was flexed downward by the weight of the ice load and contracted by its low temperature and that the basins owe something to crustal deformation. This third cause tallies with certain features not readily explained by the others. And still it is doubtful whether all these combined constitute an adequate explanation of the phenomena. Certain it is, at least, that the measure of participation of each must be determined before a satisfactory elucidation can be reached. The full solution therefore involves not only the recognition of multiple participation but an estimate of the measure and mode of each participation. For this the simultaneous use of a full staff of working hypotheses is demanded. The method of the single working hypothesis or the predominant working hypothesis is incompetent.

In practice it is not always possible to give all hypotheses like places nor does the method contemplate precisely equable treatment. In forming specific plans for field, office or laboratory work it may often be necessary to follow the lines of inquiry suggested by some one hypothesis, rather than those of another. The favored hypothesis may derive some advantage therefrom or go to an earlier death as the case may be, but this is rather a matter of executive detail than of principle.

A special merit of the use of a full staff of hypotheses coördinately is that in the very nature of the case it invites thoroughness. The value of a working hypothesis lies largely in the significance it gives to phenomena which might otherwise be meaningless and in the new lines of inquiry which spring from the suggestions called forth by the significance thus disclosed. Facts that are trivial in themselves are brought forth into importance by the revelation of their bearings upon the hypothesis and the elucidation sought through the hypothesis. The phe-

nomenal influence which the Darwinian hypothesis has exerted upon the investigations of the past two decades is a monumental illustration. But while a single working hypothesis may lead investigation very effectively along a given line, it may in that very fact invite the neglect of other lines equally important. Very many biologists would doubtless be disposed today to cite the hypothesis of natural selection, extraordinary as its influence for good has been, as an illustration of this. While inquiry is thus promoted in certain quarters, the lack of balance and completeness gives unsymmetrical and imperfect results. But if on the contrary all rational hypotheses bearing on a subject are worked coördinately, thoroughness, equipoise, and symmetry are the presumptive results in the very nature of the case.

In the use of the multiple method, the reaction of one hypothesis upon another tends to amplify the recognized scope of each. Every hypothesis is quite sure to call forth into clear recognition new or neglected aspects of the phenomena in its own interests, but oftentimes these are found to be important contributions to the full deployment of other hypotheses. The eloquent expositions of "prophetic" characters at the hands of Agassiz were profoundly suggestive and helpful in the explication of "undifferentiated" types in the hand of the evolutionary theory.

So also the mutual conflicts of hypotheses whet the discriminative edge of each. The keenness of the analytic process advocates the closeness of differentiating criteria, and the sharpness of discrimination is promoted by the coördinate working of several competitive hypotheses.

Fertility in processes is also a natural sequence. Each hypothesis suggests its own criteria, its own means of proof, its own method of developing the truth; and if a group of hypotheses encompass the subject on all sides, the total outcome of means and of methods is full and rich.

The loyal pursuit of the method for a period of years leads to certain distinctive habits of mind which deserve more than the passing notice which alone can be given them here. As a

factor in education the disciplinary value of the method is one of prime importance. When faithfully followed for a sufficient time, it develops a mode of thought of its own kind which may be designated the habit of parallel thought, or of complex thought. It is contra-distinguished from the linear order of thought which is necessarily cultivated in language and mathematics because their modes are linear and successive. The procedure is complex and largely simultaneously complex. The mind appears to become possessed of the power of simultaneous vision from different points of view. The power of viewing phenomena analytically and synthetically at the same time appears to be gained. It is not altogether unlike the intellectual procedure in the study of a landscape. From every quarter of the broad area of the landscape there come into the mind myriads of lines of potential intelligence which are received and coördinated simultaneously producing a complex impression which is recorded and studied directly in its complexity. If the landscape is to be delineated in language it must be taken part by part in linear succession.

Over against the great value of this power of thinking in complexes there is an unavoidable disadvantage. No good thing is without its drawbacks. It is obvious upon studious consideration that a complex or parallel method of thought cannot be rendered into verbal expression directly and immediately as it takes place. We cannot put into words more than a single line of thought at the same time, and even in that the order of expression must be conformed to the idiosyncrasies of the language. Moreover the rate must be incalculably slower than the mental process. When the habit of complex or parallel thought is not highly developed there is usually a leading line of thought to which the others are subordinate. Following this leading line the difficulty of expression does not rise to serious proportions. But when the method of simultaneous mental action along different lines is so highly developed that the thoughts running in different channels are nearly equivalent, there is an obvious embarrassment in making a selection for

verbal expression and there arises a disinclination to make the attempt. Furthermore the impossibility of expressing the mental operation in words leads to their disuse in the silent processes of thought and hence words and thoughts lose that close association which they are accustomed to maintain with those whose silent as well as spoken thoughts predominantly run in linear verbal courses. There is therefore a certain predisposition on the part of the practitioner of this method to taciturnity. The remedy obviously lies in coördinate literary work.

An infelicity also seems to attend the use of the method with young students. It is far easier, and apparently in general more interesting, for those of limited training and maturity to accept a simple interpretation or a single theory and to give it wide application, than to recognize several concurrent factors and to evaluate these as the true elucidation often requires. Recalling again for illustration the problem of the Great Lake basins, it is more to the immature taste to be taught that these were scooped out by the mighty power of the great glaciers than to be urged to conceive of three or more great agencies working successively in part and simultaneously in part and to endeavor to estimate the fraction of the total results which was accomplished by each of these agencies. The complex and the quantitative do not fascinate the young student as they do the veteran investigator.

The studies of the geologist are peculiarly complex. It is rare that his problem is a simple unitary phenomenon explicable by a single simple cause. Even when it happens to be so in a given instance, or at a given stage of work, the subject is quite sure, if pursued broadly, to grade into some complication or undergo some transition. He must therefore ever be on the alert for mutations and for the insidious entrance of new factors. If therefore there are any advantages in any field in being armed with a full panoply of working hypotheses and in habitually employing them, it is doubtless the field of the geologist.

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